

“MATLAB SIMULATION OF HYBRID ENERGY STORAGE SYSTEMS BY USING PMSG IN REMOTE AREA POWER SUPPLY (RAPS)”

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ABSTRACT

In rural areas, the RAPS network has been used to supply power where the utility grid is not present or not easily available. The RER are now being used in RAPS network in order to reduce the high expenditure due to use of conventional generators. The RER have gained popularity nowadays against conventional generators. Therefore, it becomes very difficult to maintain the stability and reliability of RAPS systems. So, Permanent Magnet Synchronous Generator (PMSG) is gaining attention. This work suggests the Hybrid Energy Storage Systems (HESS) such as Ultra-Capacitors (UCs) and Lithium-ion batteries to be interfaced into a PMSG based RAPS network to provide the frequency support and improve stability and reliability of the system. The UCs deal with fast changing frequency, whereas the Lithium-ion batteries provide primary frequency response. This work will help to achieve the goal of eco-friendly electrification.

KEYWORDS: PMSG-Permanent Magnet Synchronous Generator, RAPS- Remote Area Power Supply, UCs - Ultra-Capacitors, WECS - Wind Energy Conversion Systems, PCC - Point of Common Coupling, RER - Renewable Energy Resources & HESS - Hybrid Energy Storage Systems

Received: Oct 02, 2019; **Accepted:** Oct 22, 2019; **Published:** Dec 03, 2019; **Paper Id.:** IJEEERDEC20195

INTRODUCTION

The renewable energy (e.g., wind, solar) is a need of the time in order to reduce the dependent nature of fossil fuels. The main problem with renewable power generation is that it cannot be used as per demand and as per requirements. They cannot be taken away from one place to another for different purposes. The conventional energy resources, such as thermal and hydel can be used as per demand and as per requirements. The use of RER has played a vital role on the operations of RAPS systems. Therefore, it becomes very difficult to maintain the stability and reliability of RAPS network. Nowadays, it has become very difficult for conventional generators to meet the requirements of the RAPS systems for their proper functioning.

RAPS system is an independent type of network that supplies power to small rural areas. In rural areas, the grid is not available and it is impossible to extend the grid to these areas. RAPS systems are considered to be the best option for electrification and highly promoted by the Energy Access Practitioner Network launched by the United Nations Foundation to ensure universal access to modern energy service. The diesel generator sets have been widely being used in RAPS network to maintain the supply. The RER based RAPS systems have gain more popularity nowadays due to the decrement of fossil fuel reserves and the increment of prices of the fuels. The RAPS system is a small network of electricity that serves as a unique owner of a system with very simple loads. The RAPS system tends to remain away from grid or remains isolated from the main utility grid. The generators

used in a RAPS system supplies the required voltage to the network and the system maintains their load demand accordingly. The RAPS systems are somewhat similar to the 'autonomous power systems'. RAPS systems always operate in isolated or independent mode and do not take any kind of support from the utility grid. The energy storage devices are commonly being used in the RAPS system to remove the fluctuation due to RER and to improve the stability and reliability of the system.

The adoption of renewable power generators such as wind energy conversion systems (WECSs) removes the problem of frequency stability. The WECS has been developed due to their high capacity and gaining popularity in rural areas and locations where wind resource is easily or likely available. Permanent magnet synchronous generator (PMSG) based WECS with energy storage devices will be a good option for this type of requirement. Therefore, PMSG is considered to be the best due to its high torque-to-volume ratio and its operational characteristics without a gearbox. Therefore, PMSG has gained attention nowadays.

Energy storage devices like UCs and lithium-ion batteries will be a reliable option in order to improve the WECS based RAPS systems. The ultra-capacitor (UC) is a short range energy storage device due to its high efficiency and fast charging and discharging rates. These advantages of UC have led to support instantaneous load spikes. The UC is kept in order to maintain the dynamic frequency support whenever a disturbance in frequency takes place in the system. Here, in these types of areas, the capability of UC is limited with the primary frequency response that lasts less than 30 seconds. Batteries have high energy density and are considered suitable for long term frequency regulation. The drawback of batteries is that they degrade faster and reduces their cost. One of the approaches is to combine Lithium-ion batteries with UCs, that removes the drawbacks associated with the single energy storage system. Therefore, the hybrid energy storage system (HESS) may improve the frequency regulation of the independent isolated RAPS system. A Hybrid Energy Storage System (HESS) is inserted with the converters at the Point of Common Coupling (PCC) in order to improve the generation from wind turbines. Based on the Hybrid Energy Storage System (HESS), consisting of UCs and Lithium-ion batteries, the system is added on to the DC link of the entire network. The UCs provide the fast changing frequency, whereas the Lithium-ion batteries provide primary frequency response.

WORKING PRINCIPLE

The research work has to be carried out with the help of some tools like MATLAB software. So, the tool which we will be using in order to carry out our research work will be MATLAB R2013a 64 bit software. The elements like wind turbine block, PMSG (Permanent Magnet Synchronous Generator), rectifier block, inverter block, inductor, capacitor, 3-phase VI measurement block, LC filter block, ultra-capacitor block, battery block, 3-phase transformer, 3-phase RLC load block, etc. required in our work will be taken from "Sim power systems" tool box under "Sim scape" icon present in Simulink library of the MATLAB. We will be utilizing "Battery" and "Ultra-capacitors" block for hybrid energy storage systems for maintaining the power supply in the network or RAPS systems and improving the stability and reliability of the network. "Powergui" block is used as a generator to the model in order to make it run in MATLAB. We will also be utilizing "Scope" and "Workspace"-block under "Sink" icon present in Simulink library of the MATLAB in order to record the observations or responses after simulating the model. The model is made to run at 50 Hz frequency. First of all, all the blocks are initialized as per requirements and then the model is made to run to check if there are errors present in it or not. Then the Simulink model is made to run or simulate by using MATLAB R2013a 64 bit software tool. The responses are observed by the help of scope or workspace.

The HESS (UCs and Lithium-ion battery), is interfaced into a PMSG based WECS. First of all, the wind turbine rotates to generate the mechanical torque. Then, the torque is given as input to the PMSG. PMSG is used to convert the mechanical work done by the wind turbine to electrical energy. The output voltage of PMSG is given as input to the diode bridge rectifier. The diode bridge rectifier converts the input sinusoidal alternating voltage to the DC voltage and passes on to the associated network. The DC voltage is converted to alternating voltage by means of an IGBT/ diode based inverter. The energy storage devices, i.e., UCs and lithium-ion batteries are connected to the DC side, which is in between the rectifier and inverter end. It acts as a branch in between the rectifier and inverter end. The output power generation through IGBT/ diode bridge inverter is then made to pass through a three phase transformer by connecting a LC-filter in between them. The output is then provided further to the RAPS network system.

COMPONENTS

The components present in this work are as follows:-

- Wind turbine
- Permanent Magnet Synchronous Generator (PMSG)
- Diode bridge rectifier
- IGBT/ Diode bridge inverter
- Ultra-Capacitors
- Batteries
- LC filter
- Three phase transformer (Star-Delta)

Wind Turbine

A wind turbine consists of a turbine which is rotated by means of wind. The wind acts as an input to the wind turbine. The wind turbine is used to generate the mechanical torque, which is then taken as an input to get the electrical energy. The wind turbine has 2 different types of axis-vertical axis and horizontal axis. The smallest of all the wind turbines are used for providing power to traffic warning signs and charging of battery of boats. The larger turbines are used for domestic power supply purposes and have become an important source of renewable energy. Nowadays, many countries have started using wind turbines instead of using fossil fuels. The turbines can rotate in horizontal axis manner or vertical axis manner. The horizontal axis is the older one and the most common one. The wind turbines mostly have a gearbox. The wind turbines are mostly used for production of electric power commercially.

The wind turbine block in MATLAB is a function of wind speeds and pitch angle (beta). It mainly depends on the nature and speed of the wind. It is mostly used in wind farms or in areas where wind is mostly available.

Permanent Magnet Synchronous Generator (PMSG)

PMSG stands for permanent magnet synchronous generator. It is a type of generator where the permanent magnet provides the excitation field. The term synchronous refers to the fact that the rotor and stator rotate with the same speed, and permanent magnet generates the magnetic field and current gets induced into the armature. In commercial purposes, the major source of electrical energy is provided by synchronous generators.

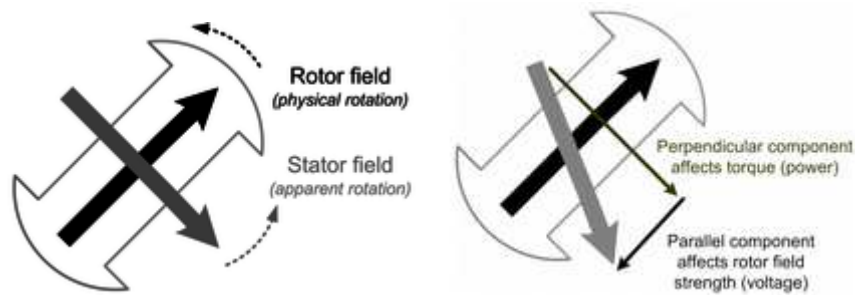


Figure 1: Rotor and Stator Fields in PMSG.

In PMSG, the "rotor" is the permanent magnet, and the "stator" is the armature, which is connected to the load end. The rotor and stator parts of the PMSG are shown in figure-1. Both the stator and the rotor maintain their synchronism with respect to their rotation. The rotor i.e. permanent magnet of the PMSG rotates due to the input given as mechanical torque by the wind turbine. The movement of permanent magnet leads to generate flux which in turn leads to generate the emf and finally leads to generate the voltage at the armature windings. The output voltages of PMSG consists of three phase voltages, which are phase shifted to each other by an angle of 120 degrees. The stator winding of the PMSG carries the three phase armature windings and is electrically displaced by 120 degrees from each other producing an AC voltage output, as shown in figure-2.

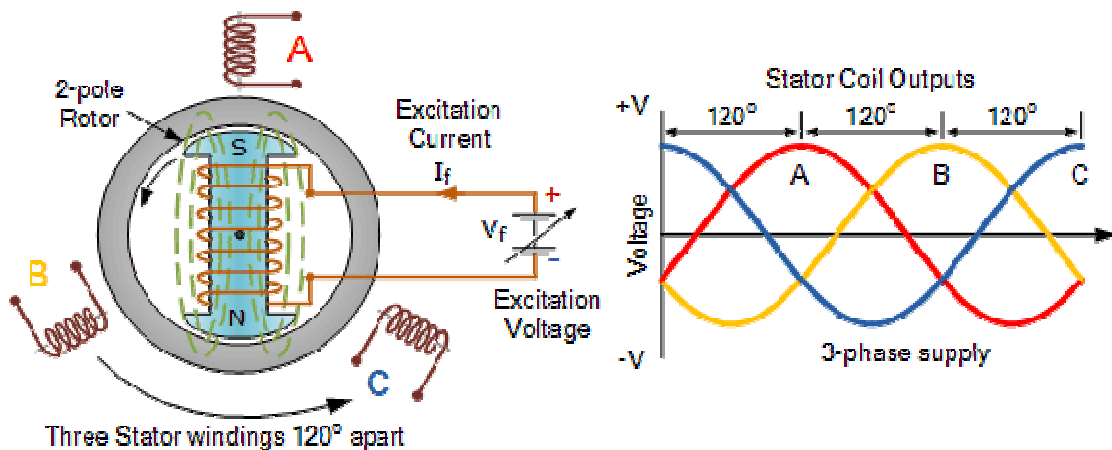


Figure 2: Construction of PMSG.

In MATLAB, the PMSG is made from Permanent Magnet Synchronous Machine block. Here, the input of Permanent Magnet Synchronous Machine is taken as mechanical torque which makes it as PMSG. The PMSG acts as a generator.

Diode Bridge Rectifier

The diode rectifier is used to convert the input AC voltage to DC voltage as the output. This process is known as rectification. A diode bridge rectifier consists of four or more diodes in a bridge circuit manner that provides the same polarity of output as that of input. It provides full-wave rectification.

The diode bridge rectifiers are implemented by using Universal bridge block in MATLAB. The Universal Bridge block consists of converters having six power switches connected in a bridge manner. The selection of switches and converters are done from the dialog box.

IGBT/ Diode Bridge Inverter

An inverter is used to convert the input DC voltage to AC voltage as the output. This process is known as inversion. This process can be achieved by thyristors, BJT, MOSFET, IGBT, etc. The output voltage of the inverter remains non-sinusoidal and rich in harmonics.

The IGBT/ diode bridge inverters are implemented by using Universal bridge block in MATLAB. The Universal Bridge block consists of converters having six power switches connected in a bridge manner. The selection of switches and converters are done from the dialog box.

Ultra-Capacitors

An ultra-capacitor is known as super-capacitor. It is an electrical component capable of holding electrical charge hundreds of times than a standard capacitor. It is useful in devices which require low current and low voltage. They are normally used in emergency radios and flashlights.

The UC requires charging before its mode of operation. Once the UC is fully charged, it can function for some period of time till it gets fully discharged or it requires charging. Once it is fully charged, then current stops flowing and the UCs output voltage is equal to the voltage of the supply. A fully charged UC will store energy till it gets fully discharged. When the UC is in discharging mode, then the stored energy gets converted into electrical energy to supply to the load present within the network. UCs are always connected in parallel manner with the network. UCs comprises of a very high value of capacitor and very less value of resistor connected in series manner. A high value of capacitor and less value of resistor are connected in series manner and the whole arrangement is connected in parallel with the circuit or the network. It always contains very high value of capacitance.

Batteries

A battery consists of one or more electro-chemical cells, which are connected to provide power to the devices like flashlights, smartphones, etc., In MATLAB, the battery (mask) is present, in which different types of batteries are found, which are connected in series with the circuit. There are many different types of batteries in MATLAB. Any one type of battery can be chosen at a time. Here, we have used lithium-ion battery.

LC Filter

An LC filter consists of inductors (L) and capacitors (C) to form low-pass filter, high-pass filter, or band-pass filter. It is a passive type of filter. A LC filter block is used to reduce noise and to remove the ripples present within the signal. It consists of one inductor and one capacitor. Here, we have chosen a branch type LC filter. They are mainly used to remove ripples from the circuit.

Three Phase Transformer (Star-Delta)

A three phase transformer or 3-phase transformer consists of three single-phase transformers. It consists of primary and secondary windings. The primary and secondary windings of a transformer can be connected in different configurations such as star or delta or as per requirement. Here, in MATLAB, we have used a three phase transformer star-delta d11 configuration and it is connected in series with the network and is used to convert the voltage from 11KV to 0.4KV, suitable to be supplied to the RAPS network.

RESULTS

The Simulation or MATLAB model is made to run in MATLAB and the responses are recorded and observed.

Rotor Speed of PMSG in rad/sec

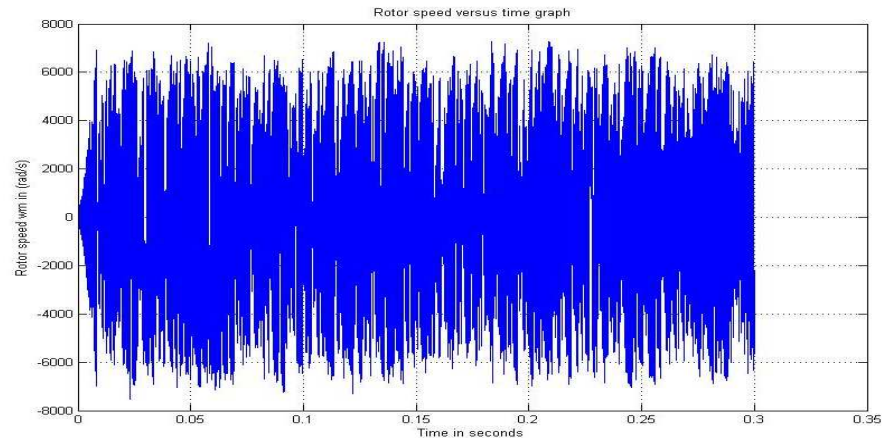


Figure 4: Rotor Speed of PMSG in rad/sec.

Rotor Angle of PMSG in rad

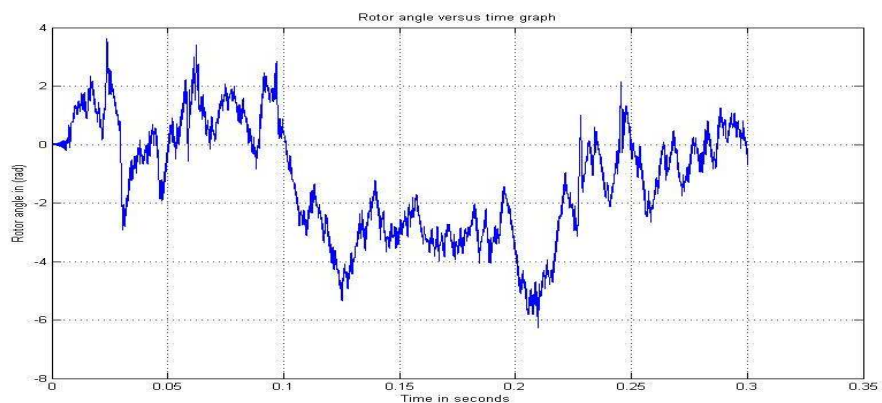


Figure 5: Rotor Angle of PMSG in rad.

Voltage Output of PMSG- $V_{\text{phase}} = 25383 \text{ Volts} = 25.383 \text{ KV}$

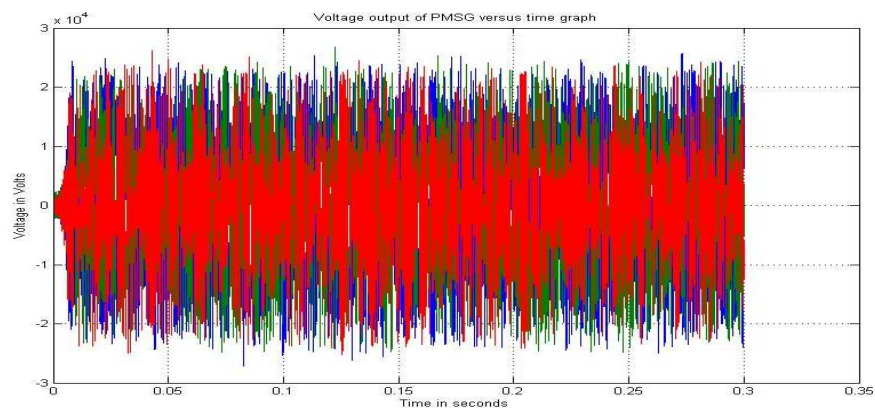


Figure 6: Voltage output of PMSG.

Voltage Output at the Inverter End- $V_{\text{phase}} = 10639 \text{ Volts} = 10.639 \text{ KV}$

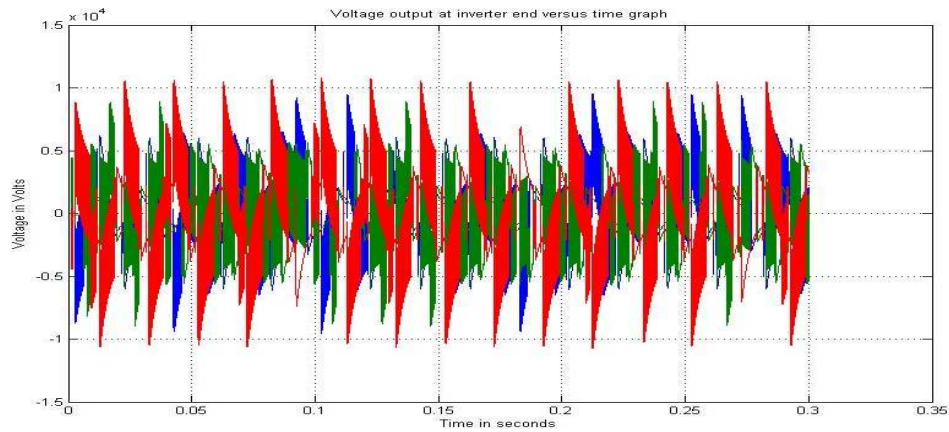


Figure 7: Voltage Output at the Inverter End.

Current Output at the Inverter End

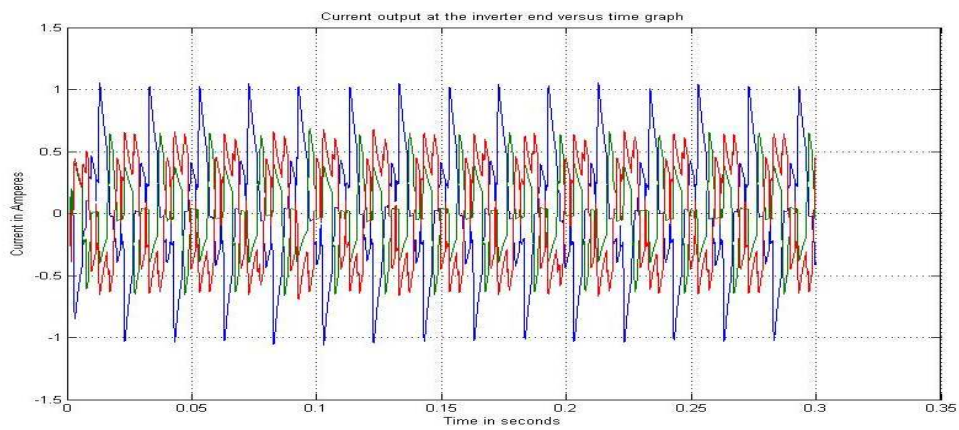


Figure 8: Current Output at the Inverter End.

Voltage at the Load End - $V_{\text{phase}} = 266 \text{ Volts}$

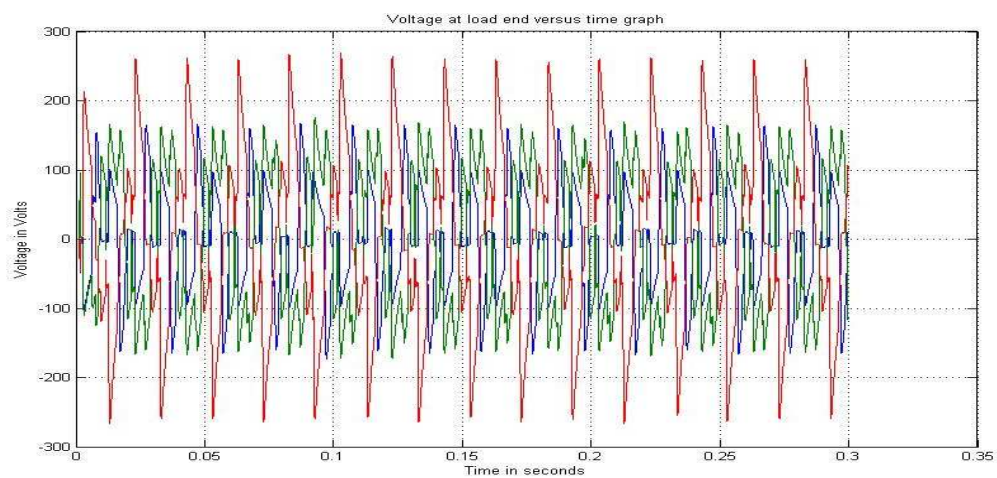


Figure 9: Voltage at the Load End.

Current at the Load End

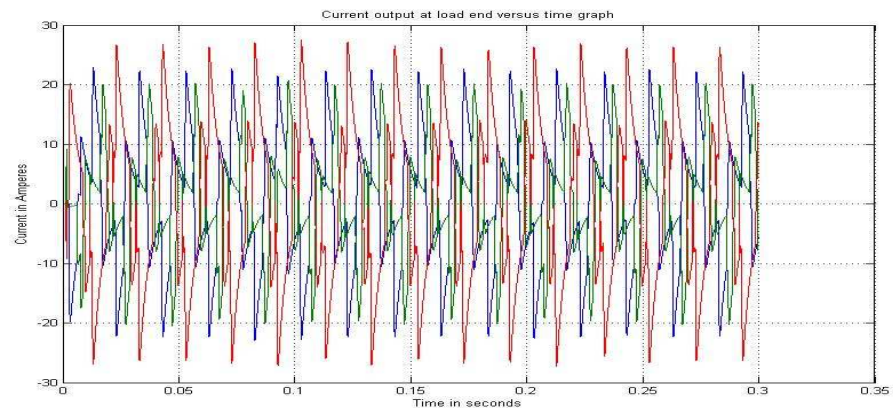


Figure 10: Current at the Load End.

Voltage at 10 m/sec wind speed - Vphase = 263 Volts

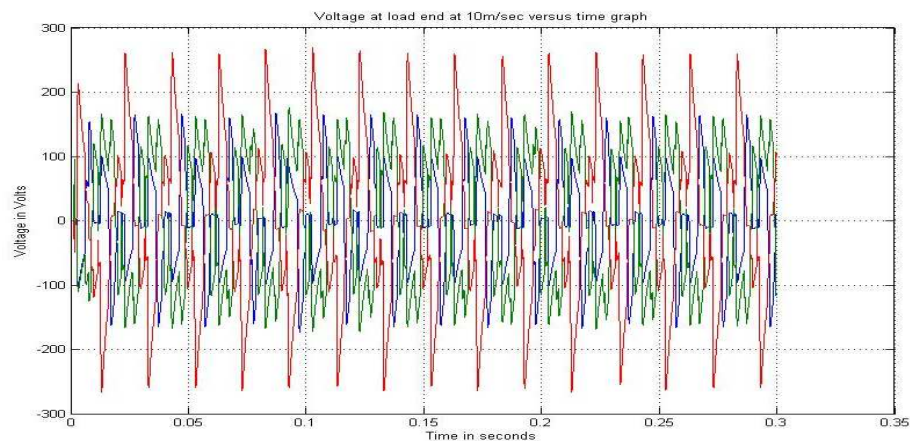


Figure 11: Voltage at 10 m/sec Wind Speed.

Voltage at 8m/sec Wind Speed - Vphase = 263 Volts

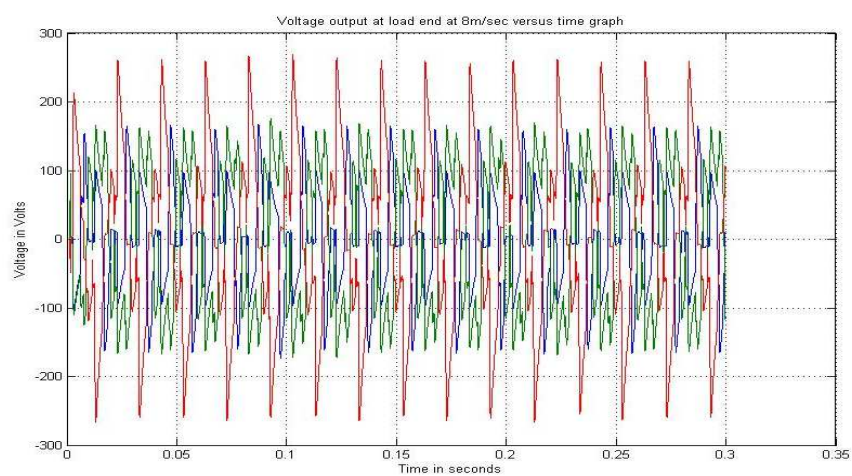


Figure 12: Voltage at 8m/sec Wind Speed.

Voltage at 5m/sec Wind Speed - $V_{\text{phase}} = 263$ Volts

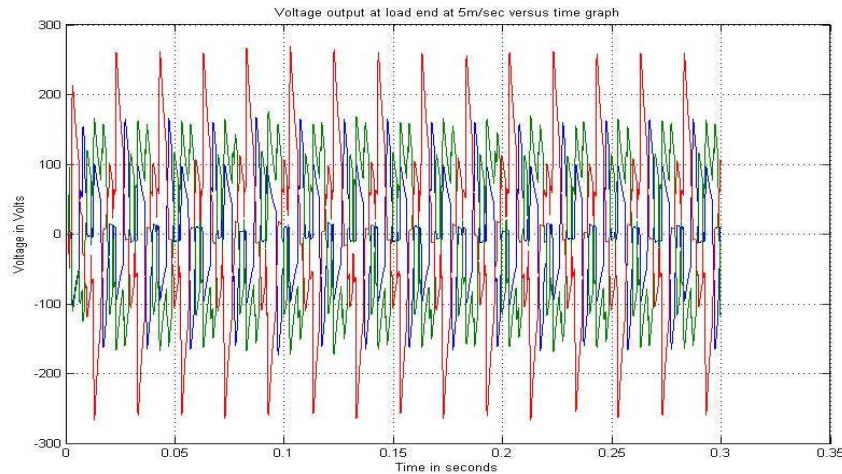


Figure 13: Voltage at 5m/sec Wind Speed.

CONCLUSIONS

The MATLAB model of Hybrid Energy Storage Systems (HESS) by using PMSG in RAPS systems is simulated and the observations are recorded and observed. The model is tested for different wind speeds at 12mt./sec, 10 mt./sec, 8 mt./sec and 5 mt./sec. The model is made to run in MATLAB and the observations are recorded and observed. The inclusion of battery and ultra-capacitors has led the RAPS systems to increase their stability. The reliability of RAPS systems has also been improved. It has also been observed that the output voltage of PMSG is 25 KV, which is the nominal voltage required for railway electrification. So, PMSG can also be used for railway electrification purposes.

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